B.C.'s Offshore Oil and Gas: a Guide to the Geology and Resources.

Introduction

Beneath the offshore regions of British Columbia are four moderately large, geologically young sedimentary basins (Figure 1) which could contain commercial quantities of oil and/or gas. Queen Charlotte Basin, Tofino Basin and Georgia Basin were partially explored in the 1960's and encouraging oil and gas shows were encountered in a few wells. On land parts of the Georgia Basin were last explored in the early 1990's. Winona Basin, located adjacent to Vancouver Island's continental slope, in water depths of up to 2000 metres, has not yet been explored.

There has been no further industrial exploration in the offshore basins since 1972 due to the imposition of moratoria on offshore drilling by the federal and provincial governments. Since then there have been considerable improvements in exploration technology and advances in our geological knowledge of these basins. In 2002 the Government of British Columbia announced that it would re-examine its position to determine if offshore oil and gas exploration and development could proceed in a scientifically sound and environmentally responsible manner. This paper is designed as a layperson's guide to the offshore basins and their hydrocarbon resource potential.

When did the basins form?

During the past 100 million years the North American continent grew through the process of welding of pieces of crust onto its western margin, resulting in the creation of the Pacific margin sedimentary basins. A sedimentary basin is a depression in the earth's surface caused by forces acting within the crust leading to subsidence. Sediments, originating outside of the basin, are transported into the depression where they accumulate, commonly to a considerable thickness. Over time, organic materials contained within the sediments, are converted to oil and/or gas.

The edges of most of these basins occur on land, but the thickest and most prospective parts for oil and gas occur offshore beneath Hecate Strait and Queen Charlotte Sound, the Strait of Georgia and outboard of Vancouver Island.

Origins of oil and gas

Oil and gas are produced through the disintegration of organic matter contained in sedimentary rocks that accumulated on the floors of ancient shallow seas. For example, the Western Canada Sedimentary Basin (Figure 1), which lies beneath the prairies and northeast British Columbia, developed during millions of years when marine waters spread eastward onto the ancient continent allowing for the accumulation of organic-rich

sediments. All of British Columbia's current oil and gas production is obtained from this basin.

As to whether a given sedimentary basin will produce oil and/or gas depends upon the basin's burial and thermal history and the origin of the organic material contained within the sediments. As the sediments become progressively more deeply buried, the temperature increases such that any contained organic matter ultimately becomes converted to coal, oil or gas. Whereas coal is formed from the remains of land-based plants, oil is derived from marine plants and animals, mainly algae, that have been 'cooked' for at least one million years at temperatures between 50° and 150° Celsius. Natural gas can be formed from both marine and non-marine organic material under a wide variety of temperatures and pressures. If the burial temperature is too high for a sufficiently long period of time, any oil that would have been generated would be converted to dry gas. Geological studies of the sediments and their organic material are able to determine the thermal and burial history of a basin to a high degree of precision and are thus able to predict whether a given basin is oil or gas prone.

Sedimentary Basins of British Columbia

Georgia Basin

The oldest of the Pacific basins is the Georgia Basin, consisting of more than 6000 metres of marine and non-marine sedimentary rocks which lies beneath the Strait of Georgia and extends beneath the coastal lowlands of eastern Vancouver Island and includes most of the Gulf Islands. To the south the basin underlies the Fraser Delta and Lower Mainland of British Columbia and the Whatcom County area of northern Washington.

The sedimentary rocks consist of sandstone, shale, conglomerate and coal, the latter derived from abundant plant debris which accumulated in coastal swamps in the Nanaimo and Comox regions. In the area of the Gulf Islands and adjacent offshore, the sedimentary rocks were deformed into long, northwesterly trending structures which could contain gas. To the south, beneath the Fraser Delta, Lower Mainland and northern Washington, several large structures have been identified, some of which might form good gas reservoirs.

Tofino Basin

The next oldest of the three basins is Tofino Basin which mainly lies beneath the continental shelf off the west coast of Vancouver Island. On land, sedimentary rocks of this basin occur on Hesquiate Peninsula along the island's west coast and on both coasts bordering the Strait of Juan de Fuca. The sedimentary strata, in excess of 3000 metres thick, consist of fine sandstone and shale which accumulated in deep water above volcanic rocks of the oceanic crust. Since their accumulation, the sediments of the basin have been deformed into a variety of structures, some of which may contain natural gas.

Queen Charlotte Basin

The youngest of the three partially explored basins, Queen Charlotte Basin, occurs mainly beneath Hecate Strait and Queen Charlotte Sound. The basin was formed by rifting due to northward motion of the Pacific Plate along the Queen Charlotte Fault, which lies outboard of the Queen Charlotte Islands. The basin fill consists of marine and non-marine sandstones and shales that accumulated above volcanic rocks. On land, sedimentary strata of the basin underlie much of eastern Graham Island from where they thicken offshore to over 3000 metres. Structures in the basin are numerous and many may form petroleum reservoirs.

Winona Basin

Winona Basin is located in more than 2000 metres of water at the base of the continental slope off northern Vancouver Island. The basin occurs above a tilted block of oceanic crust where more than five kilometres of very young sediments have accumulated. Because of the depth of water this basin has been only cursorily studied and, to date, few structures have been identified that could contain hydrocarbons.

History of Exploration

Geological and geophysical petroleum exploration of these basins has occurred at an inconsistent pace since the beginning of the last century. The most vigorous and extensive exploration was conducted by Shell Canada Ltd in the offshore portions of Tofino and Queen Charlotte basins in the mid to late 1960s, culminating in 6 wells drilled in the former basin and eight in the latter basin. Additional marine seismic surveys were carried out by Chevron Canada Limited in 1971.

Four wells have been drilled into Tofino Basin strata on the Olympic Peninsula of Washington. In addition to 23 wells drilled in the Fraser Lowlands of Georgia Basin, 95 wells have been drilled in the U.S. portion of the basin, the majority of which are shallow and probably drilled as water wells. Several slim-hole wells have tested the sedimentary strata in the Nanaimo, Parksville and Comox regions of Georgia Basin.

Given that the totality of this exploration in the three basins was not extensive, no commercial quantities of hydrocarbons have been found. Before and since the implementation of the moratoria on offshore drilling the federal government and universities have conducted geological and marine geophysical studies, including gravity, magnetic and seismic surveys, in the four basins.

Current Quality of Knowledge and Exploration Capability

At the time when most of the above exploration programs were conducted the concept of plate tectonics was in its infancy and not everywhere accepted. Since then much has been learned about the origin and architecture of continental margin sedimentary basins such that new exploration programs would be designed in a completely different way and employ technologies unavailable to the petroleum companies several decades ago.

Modern seismic exploration techniques are highly sophisticated, allowing exploration companies to identify potential hydrocarbon-bearing drilling targets with great accuracy and to improve drilling success rates by as much as 50% or more. Thus, fewer wells need to be drilled to find a given prospect and production per well can be greatly increased. Moreover, our understanding of the origins of petroleum and the many circumstances that control its development have increased greatly. The capacity to provide estimates of petroleum potential in any given sedimentary basin has improved together with increased geological knowledge on similar petroleum-bearing basins around the world with which they can be compared. Sophisticated statistical techniques are employed to estimate these potentials such that at a given level of certainty, or probability, an estimate of recoverable volumes of oil and or gas can be made.

Estimates of Petroleum Potential of B.C.'s Offshore Basins

Introduction

In 2001 the Geological Survey of Canada published its estimates of the petroleum resource potential of British Columbia's offshore sedimentary basins (Table 1). Before discussing that report it is important to understand the meanings of terms employed to describe the potential of the four basins.

- *Resource* refers to all hydrocarbons known or inferred to exist in a given basin.
- *Reserves* are those portions of the resource which have been discovered and are known to exist.
- *Potential* represents the portion of the resource not yet discovered but inferred to exist.

Since no oil or gas pools have yet been discovered in any of the Pacific basins, any discussion of their numerical volumes refers to potential or undiscovered volumes. At present there are no petroleum reserves in our Pacific offshore basins. Abbreviations used in this report are as follows: x $10^9 m^3$ = billions of cubic metres; x 10^9 bbl = billions of barrels; TCF = trillions of cubic feet.

The degree of reliability of an estimate of the petroleum potential of a given basin depends upon the amount of geological knowledge about the basin, its so-called 'exploration maturity'. The more that is known of a given basin, the more reliable the estimate of its petroleum potential. The volume of oil and gas that any basin may contain depends upon the degree of coincidence of many factors including its thermal history, the presence of petroleum source rocks such as organic-rich shales, the presence and sizes of structures into which oil or gas can migrate and be confined to form a pool or reservoir, and many other variables. The application of probabilistic statistical techniques to these independent variables results in the construction of curves which show the amount of oil or gas in a basin at any value of probability from 0% to 100%. For example, the probability curve shown in Figure 2 represents the oil potential of a hypothetical basin. At values of high probability (70% or greater) the amount of estimated resource is low as compared to those of low probability (30% or less) where resource volumes are estimated to be considerably greater.

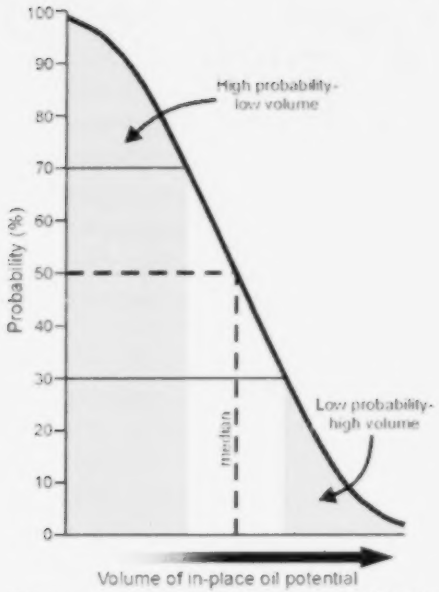

Figure 2. A probabilistic curve for the volume of oil contained in a hypothetical basin.

Built into this process is the assignment of statistical risk factors which put constraints upon the occurrence of any given variable and other non-variable factors which are important to petroleum generation and accumulation. The number that is normally chosen to describe the amount of petroleum resources in a basin is at the 50%, or median value of probability. By comparison with the geological attributes of other, similar basins throughout the world, which developed in like geological settings, one can get a sense of the degree of confidence that can be put in the estimate.

Petroleum Potential of Georgia Basin

The Geological Survey of Canada's estimate of the total gas potential for the combined Canadian and American portions of Georgia Basin, at its 50% median level of probability, is $185 \times 10^9 m^3$ (= 6.5 TCF) distributed in 230 fields; about 76% of the estimated amount would occur in Canada. No oil potential has been estimated for the basin due to a too-high temperature thermal history for the lower part of the basin which is expected to contain dry gas, and the non-marine organic character of the sediments in its upper part. For comparative purposes, the total basin median gas potential stated above amounts to about 8% of the known original in-place gas reserves of northeast British Columbia.

Petroleum Potential of Tofino Basin

The 50% probability median estimate of the gas potential of Tofino Basin is $266 \times 10^9 m^3$ (9.4 TCF) distributed in 41 fields. This amounts to about 12% of the original in-place gas resources of northeast British Columbia. Assuming an even distribution of the resource, 85% of this volume would occur within Canadian jurisdiction. Geochemical data

obtained from organic material obtained during drilling in the 1960s suggest that the basin is gas prone, therefore no oil estimate was made. Of four wells drilled into the basin on the Olympic Peninsula in Washington, one reported a gas flow of 1416 m^3/day. In the six offshore wells drilled by Shell Canada Ltd., two encountered indications of gas. Although there are significant structures within the basin which could form reservoirs, some of these may be due to geologically recent submarine slides.

Although not part of Tofino Basin, oceanic sediments in deep water near the base of the continental slope to the west contain large amounts of frozen methane gas, and, at least locally, trace amounts of oil. As organic-rich sediments become accreted to the edge of the continent as a consequence of subduction of oceanic crust, biogenic methane becomes trapped beneath the sea floor at the base of the continental slope. There low temperature and high pressure allow the material to stabilize in a frozen state, forming a substance called clathrate. The volume of this hydrocarbon is very large and may be commercially exploitable at some time in the future.

Petroleum Potential of Queen Charlotte Basin

Of the four Pacific margin, offshore basins, Queen Charlotte Basin is by far the most prospective. The Geological Survey of Canada's median estimates are: 1.56 x $10^9 m^3$ (9.8 x 10^9 bbl) of in-place oil and 734 x $10^9 m^3$ (25.9 TCF) of in-place gas. These resources are expected to be contained within 103 oil fields and 120 gas fields. Unlike the other two basins, Queen Charlotte Basin's resource potential occurs within several sedimentary successions, each of which have good source rocks and reservoir structures and thermal histories ideal for petroleum generation. Moreover, its tectonic setting involving rifting adjacent to the plate-bounding Queen Charlotte Fault is similar to other productive continental margin basins such as Cook Inlet in Alaska which has been producing oil and gas since 1967. Several indications of oil have been encountered in exploratory wells both on land and offshore. In addition over 50 sites of oil, tar or natural gas seeps have been documented in surface outcrops on the Queen Charlotte Islands.

In comparison to the original in-place volumes in northeast British Columbia, Queen Charlotte Basin's in-place oil estimate is about five times greater, and its in-place gas estimate is about 37% of the known original provincial resource.

Petroleum Potential of Winona Basin

No estimates of the petroleum potential of Winona Basin have been made. Although adequate source and reservoir rocks may be present, only geophysical information is available on the basin. While water depths in excess of 2000 metres are no longer a hindrance to drilling, much more geophysical work is needed to determine the attractiveness of this basin to exploration.

Conclusion

It is important to emphasize that the values given of petroleum resources in the three main Pacific margin basins are estimates only. Although they are based upon current geological knowledge including valuable well log records from the 1960's drilling, and are obtained by the application of rigorous statistical techniques, only further exploration can confirm or negate their validity. In Queen Charlotte Basin the fact that none of the 8 offshore wells drilled to date has encountered significant resources suggests that the exploration risk could be high, however, in historical terms, success rates in frontier basins are often initially low. For example, 36 wells were drilled on the Grand Banks of offshore Newfoundland before Hibernia was found and 16 wells were drilled in Cook Inlet, Alaska before the first field was discovered.

Although there are many factors which determine the type and volumes of petroleum accumulations, many of which must occur in concert with one another, of the four Pacific margin basins, Queen Charlotte Basin displays a serendipitous coincidence of many necessary criteria and is the most prospective.

Table 1: Oil and Gas Resource Potential of the British Columbia Offshore Basins

The table below shows the median value estimates of the petroleum potential of the west coast offshore basins.

The Queen Charlotte Basin is by far the most prospective of the four basins, estimated to have world-class potential for both oil and gas. Queen Charlotte Basin's gas potential is about 37% of the known original in-place resource of northeast British Columbia, whereas its oil potential is about five times greater.

By way of comparison, Georgia Basin and Tofino Basin respectively are estimated to contain 8% and 12% of the original, in-place gas resources of northeast British Columbia.

Based on the available geological information the Geological Survey of Canada inferred that there is little or limited oil potential in the Georgia, Tofino and Winona basins and no oil assessments were prepared.

Resource Type Median estimate	**Georgia Basin**	**Tofino Basin**	**Queen Charlotte Basin**	**Winona Basin**
Oil	No estimate	No estimate	1.56 billion m^3 (9.8 billion barrels)	No estimate
Gas	185 billion m^3 (6.5 trillion ft^3)	266 billion m^3 (9.4 trillion ft^3)	734 billion m^3 (25.9 trillion ft^3)	No estimate

m^3 = cubic metres. 1 barrel = 42 US gallons